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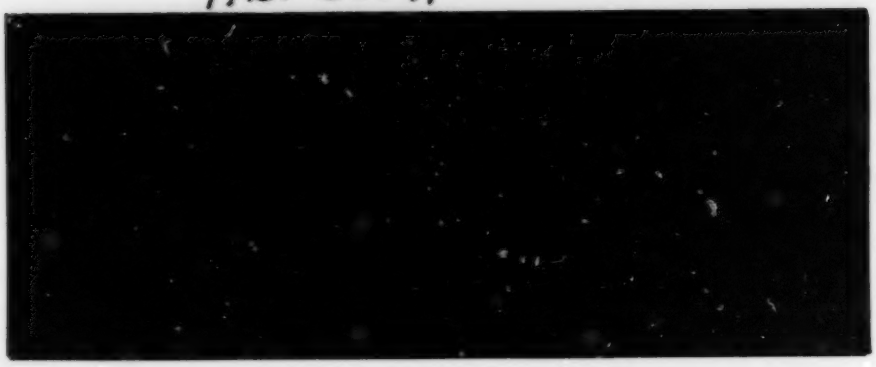

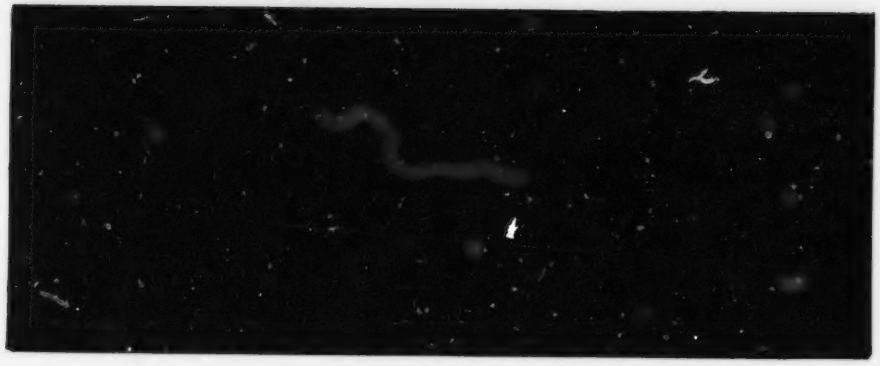

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Executive Summary

S-86-01-0008

AN EVALUATION OF WHEAT IN FEEDING MARKET PIGS

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Feeding trials with 200 market pigs provided responses in terms of growth rate, efficiency of feed utilization and carcass quality for comparing five high energy cereal grains (three types of wheat, hulless barley and corn) with regular barley when fed in mixtures or as the sole grain and when fed with either soybean meal or canola meal. The high energy grains differed widely in protein content but were rather similar in digestible energy content. Increasing dietary levels of such grains improved daily gain and efficiency of feed utilization but caused increased fat deposition and lower carcass quality. Baseline data are provided for assessing the economic implications of ingredient choices when formulating rations for market pigs.

Summary

AN EVALUATION OF WHEAT IN FEEDING MARKET PIGS

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Pig production in Western Canada is based on barley. When wheat was in surplus or damaged it has at times been economical to use. Wheat is palatable and efficiently utilized by pigs but research several decades ago showed that the feeding of wheat could reduce carcass quality and market returns.

Several factors have led to renewed interest in the feeding of wheat. The development of high yielding, medium quality wheat cultivars that might be more generally competitive in price with good feed barley is the main factor and comparison of such wheat with spring and winter types could be of value. A second factor pertains to possible expansion of the use of canola meal, which is lower in crude protein and digestible energy than soybean meal, in diets based on grains of relatively high energy content. A third factor pertains to genetic changes that have occurred in the typical commercial pig with its more rapid rate of gain and increased tendency toward leanness of carcass compared with pigs of an earlier era. Finally, it is of interest that the NRC (U.S.A.) nutritional standards call for dietary digestible energy values that cannot be achieved in barley-based diets but are attainable with corn-soybean meal diets.

Feeding trials involving 200 market pigs fed from 23 to 100 kg provided comparative evaluations of three types of wheat (hard red spring, Katepwa; winter, Norstar; medium, HY320), hulless barley (Tupper) and yellow corn as high energy grains. Each was blended with regular barley (Johnston) to provide 0, 25, 50, 75 and 100% of the grain portion of the diet. Each barley-high energy grain blend was further subdivided to test soybean meal and canola meal as the main protein supplement. The results were assessed in terms of rate of gain, efficiency of feed and of digestible energy utilization, as well as carcass quality.

The high energy grains differed widely in protein content (7.66 to 13.22%) and in essential amino acids but supplementation with either soybean meal or canola meal to meet NRC protein requirements provided adequate essential amino acids except for lysine in some cases. Canola meal was generally equal to soybean meal except in situations in which digestible energy was a limiting factor.

Increasing proportions of high energy grains resulted in faster daily gains relative to barley and this effect, somewhat surprisingly, was more pronounced in the finisher period than in the grower period. In contrast, and perhaps in explanation of this finding, increasing digestible energy levels in grower diets resulted in increasing amounts of digestible energy being consumed per unit of liveweight gain. This indicates a higher fat content of the gains. This trend did not occur in the finisher period and may indicate a possible amino acid deficiency, probably lysine, during the grower period.

Increasing proportions of high energy grain in the diet improved the efficiency of feed utilization and the dressing percentage of the pigs at slaughter however there was increased carcass fat, decreased lean yield and lowered carcass quality. Minor differences occurred among the high energy grains used. The results of this study provide useful baseline data for estimating the effects of kind of grain used on rate and efficiency of gain and on carcass quality, and similarly with respect to the choice of protein supplement. By applying the appropriate costs of cereal grains and protein supplements, and the market value of hogs, the economic implications of specific cost-price situations may be determined.

AN EVALUATION OF WHEAT IN FEEDING MARKET PIGS

J.M. Bell and M.O. Keith

FINAL REPORT
ON
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Background and Objectives

Barley has been the mainstay of pig production in Western Canada throughout this century. In times of wheat surpluses and when low-grade wheat was available, wheat was used as part of the grain component of pig rations. Little research, however, has been done in Canada on wheat as a pig feed since the work of E.W. Crampton and associates over 40 years ago at Macdonald College, Quebec, which showed that while wheat was palatable and efficiently utilized by pigs it led to overfinish, reduced carcass quality and lower monetary returns.

Recent experiments have reaffirmed the high palatability and high digestibility of wheat for pigs (Froseth et al. 1981) but these reports and others (Anderson and Bell 1983a, 1983b; Bell and Anderson 1984a, 1984b) have demonstrated important cultivar differences. Very little information exists on the feeding value of the new high yielding 3M-type wheats such as HY-320.

The successful development of hulless barley cultivars has presented another alternative high energy grain for pig feeding. The digestibility of energy and protein in hulless barley has been evaluated (Mitchell et al. 1976, Bhatty et al. 1979, Bell et al. 1983) and found to contain relatively high levels of digestible energy (DE) and digestible protein. However, hulless barley had not been evaluated in grower-finisher feeding trials, nor compared with other high energy, low fibre grains such as wheat or corn.

In addition to the new types of high energy grains becoming available for feeding to pigs, the performance and carcass quality of commercial pigs in Canada has improved markedly in recent decades (Fredeen 1984) as a result of the indexing system of carcass grading introduced in 1968 and the increasing concentration of pig production in specialized production units. It is therefore possible that increased daily consumption of DE and the associated faster growth rates will not lead to the same degree of overfinish encountered several decades ago when feeding wheat. It is also of interest that the dietary levels of DE indicated as required in the U.S. National Research Council (NRC) (1979)

tables of nutrient requirements of swine cannot be achieved using diets based on barley.

A further complicating factor when attempting to meet the DE requirements of growing-finishing pigs arises when attempting to use canola meal (CM), to replace soybean meal (SBM), because of its relatively low DE value associated with its high fibre (hull) content.

The objectives of this research were (a) to evaluate three types of wheat (HY-320, hard red spring and winter) and hulless barley as partial or complete replacement of barley in grower-finisher diets for pigs, (b) to assess and compare SBM and CM as protein supplements for each of the grain combinations, (c) to compare barley and barley-high energy grain diets with those based on corn in order to compare Canadian and US-type formulations and (d) to assess responses in terms of comparative rates of gain, daily feed intakes, efficiency of feed utilization, carcass quality and economic returns.

Experimental Methods

This research was conducted in two phases (Exp. 1 and 2) because of limitations of pen space. Each phase involved a factorial design enabling study of all possible interactions among treatments as well as the main treatment effects.

In Exp. I Katepwa (hard red spring) wheat was compared with Norstar (winter) wheat. Each wheat was included in the diet at 0, 25, 50, 75 and 100% replacement of Johnston barley. As a further cross-treatment each of the five diets involving each type of wheat was supplemented as required with SBM or CM to provide grower diets containing about 16.3% crude protein (CP) and finisher diets containing about 14.3% protein. The diets were supplemented with lysine, minerals and vitamins to meet or exceed NRC (1979) requirement levels (Table 1). The amount of CM in the diets was limited to approximately 20% because of its relatively low DE value compared with SBM. Diets based on corn required about 23% SBM and the corresponding amount of CM of about 32% would have exceeded CM levels previously tested with grower-finisher pigs. It is also observed that the CP levels in CM II and the hulless barley were below normal values, apparently the result of environmental factors since low CP values in CM were typical of the crop year involved.

Eighty crossbred barrows were randomly allotted in four replicates to the 20 diets at 23 kg initially. The finisher diet was introduced at 57 kg, the pigs were slaughtered at 100 kg and carcasses were evaluated (Fredeen 1976). The pigs were individually fed three times daily during the grower stage (0700, 1100, 1500 h) and twice daily thereafter (0700, 1500 h). Feed consumption and pig weights were recorded weekly.

In Exp. 2, HY-320 wheat, Scout hulless barley and corn were the high energy grains tested (Table 2). In other respects the experimental

design was similar to that of Exp. 1, except that 120 pigs were involved.

Prior to diet mixing the wheat was processed in a roller mill set to produce a coarse modulus with a minimum of "fines" and the barley and corn were processed in a hammermill using a 6.35 mm screen. Subsequent to processing, the samples were evaluated for texture using standard sieves.

The pigs used in this experiment were of Yorkshire x (Landrace x Yorkshire) cross breeding, of minimum-disease status and obtained from the Prairie Swine Centre, University of Saskatchewan. The experimental barn had been thoroughly cleaned, disinfected and fumigated prior to arrival of the pigs for each experiment.

The following analytical methods were employed: moisture, ether extract, ash, CP and lignin, Association of Official Analytical Chemists (AOAC) (1980); CP, AOAC (1980), modified according to Sher (1955); gross energy, a Parr adiabatic calorimeter Model 1241 was used; acid detergent fibre, Goering and Van Soest (1970); neutral detergent fibre, Mongeau and Brassard (1979); glucosinolates, Heaney and Fenwick (1980) using benzyl glucosinolate as the internal standard and a response factor of 1.8 to calculate hydroxyindolyl glucosinlate concentrations.

Concentrations of amino acids, except tryptophan, were measured following 20-h hydrolysis in 6 N HCl on a Beckman 121 amino acid analyzer using a 2.5 h single column analysis and W-2 resin. Methionine and cystine were determined after performic acid oxidation by the method of Moore (1963) modified to exclude the use of hydrogen bromide. Tryptophan was measured after alkaline hydrolysis (Miller 1967). All assays were carried out in duplicate.

Analysis of variance and covariance of growth rates, feed utilization (as the independent variable) and carcass quality were performed according to Kim and Kohout (1975) and mean differences were tested using the k-ratio test of Waller and Duncan (1969) appropriate for the experimental design employed here (Chew 1977). The effects of different proportions of barley and high-energy grains were tested for linear and quadratic effects by regression methods (Steel and Torrie 1980).

Results and Discussion

The chemical composition of the major ingredients used in the two experiments (Table 3) revealed a wide range of CP values among the cereal grains (7.66 to 13.32%). There was a similar wide range in lysine contents (0.27 to 0.45%). These two aspects were the dominant factors in determining the diet formulations (Tables 1 and 2) since the gross energy and estimated DE values of the five high energy grains were relatively similar.

The evaluation of texture (Table 4) showed that Katepwa and Norstar wheats were relatively similar to each other and from batch to batch but HY-320 wheat tended to be coarser than the other two wheats. Scout (hulless) barley apeared to grind relatively coarsely and produced fewer fines (<0.84 mm) than most other cereals. Corn ground more finely than the other cereals and had from 26 to 44% of its particles below 0.84 mm in size. Johnston barley samples were variable; batches used in Exp. 2 diets tended to be coarser.

Experiment 1

The nutrient composition of the grower diets used in Exp. 1 as determined by analysis (Table 5) shows that CP levels in Katepwa wheat diets, with one exception, met or exceeded NRC (1979) requirements for 20 to 35 kg pigs. With Norstar wheat, all diets except one were below 16% CP. However, since the grower diet was fed until pigs weighed 57±2 kg and since the NRC requirement tables indicate 14.0% CP for pigs of 35 to 60 kg weight it seems improbable that a deficiency of protein would occur. This conclusion is confirmed by the amino acid values. The four amino acids (Table 5) most likely to be limiting in such diets, especially lysine, all exceeded NRC requirements. All other essential amino acids also exceeded NRC requirement levels.

In contrast to the conclusion that amino acid levels in the diets of Exp. 1 may have been adequate relative to NRC levels, there is evidence that the NRC (1979) lysine specifications may be too low. Recent findings in our laboratory (Bell et al. 1988) with similar pigs, diets and management, indicated linear improvements in daily gain and efficiency of feed utilization as dietary lysine levels increased from 0.77 to 1.07% (dry matter basis). This agrees reasonably well with the findings of Yen et al. (1986) and the Agricultural Research Council of the U.K. (1981). It is therefore possible that dietary lysine levels may not have been adequate to obtain maximum performance in the pigs during the grower period.

The estimated DE contents of the diets (Table 5) shows that diets with Johnston barley as the only grain contained from 2943 to 2982 kcal kg^{-1}, whereas diets using only wheat contained about 3100 kcal. Diets employing SBM contained slightly more DE than those containing CM and the difference was larger (1.43 vs 0.6%) with Norstar wheat which required more protein supplement than with Katepwa wheat.

The finisher diets for pigs 57 to 100 kg were analyzed similarly and found to exceed NRC (1979) requirements in all respects except for DE levels. The probability of encountering nutritional deficiencies was therefore small except in regard to DE.

The growth and feed utilization responses of pigs during the growing period (Table 6) showed no overall difference between Katepwa and Norstar wheat, nor between SBM and CM protein supplements. There was,

however, an interaction between wheat and supplements ($P<0.05$) indicating that pigs fed Norstar wheat grew faster and had better feed:gain ratios if SBM was used than when CM was used. It is possible that this was related to the lower CP level in Norstar wheat, thereby requiring more protein supplement as the proportion of wheat in the diet increased. The use of CM would decrease the dietary DE level, whereas SBM would tend to increase the DE level.

Adjusted daily gains were determined using covariance and regression methods (Steel and Torrie 1980), when significant ($P<0.05$) correlations were found between daily feed intake and daily gain. While adjustment was warranted in this experiment the adjusted daily gains showed the same trends as the observed gains, indicating that within-group variations in daily feed intake did not affect the outcome of the treatment comparisons.

The responses to the different percentages of barley in the grain mixtures were tested by regression methods. When the correlation coefficient was significant ($P<0.05$) the range of response was drawn from the regression relationship. There were no general effects on daily gain, daily feed intake, feed:gain ratio or adjusted daily gain but an interaction effect ($P<0.05$) showed that when CM was used adjusted daily gains increased as the percentage of barley in the diet decreased (670 to 707 g) but there was no effect when SBM was used (706 vs 706g).

During the finisher period (57 to 100 kg), as in the grower period, there were no overall differences between Norstar and Katepwa wheats (Table 7) but there were interactions involving wheat and protein supplement. Pigs fed Norstar wheat showed no difference between SBM and CM in either feed:gain ratio or adjusted daily gain but pigs fed Katepwa wheat performed better when CM was used. It was also found, when SBM was used, that Norstar wheat was more efficiently used than Katepwa wheat and promoted better daily gains (adjusted to constant feed intake).

There were strong linear effects ($P<0.01$) between percentage of barley in the diet and daily gain as well as with feed:gain ratio and adjusted daily gain (Table 7). As percentage of barley decreased from 100 to 0% the feed:gain ratio decreased from 3.67 to 3.30 and adjusted daily gain increased from 793 to 890 g. There were no significant interactions involving percentage barley and other treatments so the above relationship apears valid with both kinds of wheat and both kinds of protein supplement.

There were no differences between the two cultivars of wheat in terms of the overall average daily gains (Table 8), average daily feed intakes or feed:gain ratios but when gains were adjusted for feed intake differences, Norstar wheat was superior to Katepwa. However, the general responses did not prevail when the wheats were examined according to the protein supplement used. Norstar was superior only when supplemented with SBM. Likewise, the general responses over the 23 to 100 kg pig

weight range were similar for SBM and CM but when fed with Katepwa wheat CM yielded higher adjusted gains than SBM and the reverse was true with Norstar wheat.

Decreasing percentages of barley (Table 8) resulted in a linear increase ($P<0.01$) in daily gain and in adjusted daily gain, as well as a linear improvement in feed:gain ratio ($P<0.01$). The regression values for 100 and 0% barley were 740 and 807 g adjusted daily gain and 3.23 and 2.98 feed:gain ratios, respectively. Interaction effects indicated that the improvement in feed:gain ratios associate with decreasing the percentage of barley was greater when CM was used than with SBM. Similarly, adjusted daily gains improved more with CM than with SBM as the percentage of barley in the diet decreased.

Carcass traits (Table 9) revealed significant effects for the main experimental treatments and for three first order interactions for several of the traits. The average carcass weight of pigs fed Katepwa wheat was greater than that for Norstar, however the liveweight prior to slaughter was also greater (101.7 vs 100.5 kg, $P<0.05$). Covariance analysis indicated a significant correlation between final livewight and grade index but for no other criteria, thus the overall differences in final liveweight found between the two wheats did not affect the outcome of treatments elsewhere in this experiment and did not change the average index values for the two wheats.

Decreasing percentages of barley in the diet resulted in increasing dressing percentage, carcass weight, backfat thickness and decreasing lean yield, loin thickness and grade index (Table 9). The changes were linear ($P<0.05$) and the magnitude of change, progressing from all-barley to all-wheat diets was as follows: dressing percentage, 76.5 to 78.3; carcass weight, 77.5 to 79.0 kg; backfat 21.8 to 27.4 mm; lean yield 49.3 to 47.6%; loin thickness 52.3 to 49.00 mm and grade index 105.5 to 102.4.

The choice of protein supplement affected carcass traits (Table 9). Pigs fed CM had less backfat and higher lean yield but the observed improvement of 1.3 percentage points in grade index was not significant ($P>0.05$).

Each of the main experimental treatment effects must be interpreted in terms of their interactions with other treatments. The responses to cultivar of wheat were not affected by the kind of protein supplement used, nor were the responses to protein supplements affected by the cultivar of wheat in the diet. This is evident by the lack of significant interactions for wheat x supplement (Table 9). In contrast, however, the two wheats gave different results when fed in the various combinations with Johnston barley. Norstar resulted in no increase in backfat as the percentage of wheat in the diet decreased whereas there was a marked increase with Katepwa wheat from 20.2 mm to 28.6 mm as determined by regression. Similar responses were obtained for lean yield

(48.9 to 47.2), loin thickness (54.1 to 48.6) and grade index (106.8 to 101.6).

Whereas the general effect of increasing the amount of wheat in the ration was an increase in dressing percentage, this effect was associated with diets containing SBM, where dressing percentage increased from 76.0 to 79.3, compared with corresponding values of 77.0 to 77.3 for diets containing CM, using linear regression values.

Experiment 2

The nutrient composition of the diets used in Exp. 2 (Table 10) showed that CP, isoleucine, methionine + cystine, tryptophan and lysine levels exceeded NRC (1979) levels, except for the value of 15.94% CP for the corn and CM diet at 50% barley. The estimated DE values showed various trends depending on the type of protein supplement and the high energy grain used in the diet. In generai, the DE content increased as the percentage of barley decreased but the maximum DE value varied from 2994 to 3256 kcal DE per kg of feed. When HY-320 wheat and CM were used, decreasing the percentage of barley had no effect on DE content. It is therefore possible that differences in pig performance might reflect differences in DE intake.

The analysis of the pig responses during the grower period (23 to 57 kg) revealed very similar results when comparing the three series of diets based on Johnston barley replaced by various levels of either HY-320 wheat, hulless barley or corn (Table 11). The 3% apparent advantage in observed daily gain for pigs fed diets containing corn blends was not significant ($P>0.05$) but was significant following adjustment by regression for within-group variation in daily feed consumption.

Since daily feed intakes were similar among the high energy grain treatments and while feed:gain ratio and adjusted daily gains were superior (Table 11) for pigs fed diets containing some corn, it may be concluded that diets containing corn were nutritionally superior to those containing either wheat or hulless barley. Since dietary levels of protein and amino acids were safely above NRC (1979) requirement levels and vitamins and minerals were also adequate, it is probable that higher digestibility of energy in corn and its higher oil (ether extract) content may have given it marginal superiority over wheat and hulless barley.

Varying the percentage of barley in the grain mixture (Table 11) from 100% down to 0% resulted in about 3.6% greater daily gain. The correlation coefficient (r) was -0.89 between adjusted daily gain means and the percentage of barley in the grain mixture. Similarly there was a high correlation ($r=0.93$) between the mean feed:gain ratios and the percentage of barley in the mixture. The regression relationship indicated that about 4% less feed was required per unit of weight gain when barley was completely replaced by wheat, corn or hulless barley.

The use of CM (Table 11) resulted in about 5% slower daily gain than with SBM and about 3% slower in terms of adjusted daily gains. Likewise, pigs fed CM required about 3.6% more feed per unit of gain.

There were no significant interactions among the main effects for any of the criteria shown in Table 11.

In the finisher period (57 to 100 kg) the growth rates and feed intakes of the pigs were very similar when diets based on the three high energy grains were compared (Table 12). Corn showed little, if any, advantage over wheat or hulless barley ($P>0.05$).

Contrary to the findings during the grower period, pigs grew faster ($P<0.05$) as the percentage of high energy grain in the diet increased. Based on regression analysis of adjusted daily gain and percentage of barley in the diet ($r=-0.86$), pigs fed diets based on high energy grain gained 12.5% faster and used their feed 11.5% more efficiently than those fed on straight barley diets. There was a significant linear relationship ($P=0.006$) between daily gains and percentage of barley in the diet, and similarly with feed:gain ratio ($P=0.0002$).

The adjusted daily gains increased from 857 g to 962 g as the percentage of barley decreased from 100 to 0% (Table 12), using values determined by the regression method. Similarly the feed:gain ratio improved from 3.56 to 3.15.

The results obtained from the comparison of protein supplements were similar to those obtained during the grower period. Pigs fed CM gained about 3% more slowly than those fed SBM and were about 3% less efficient in feed utilization.

The differences between SBM and CM were not significant in terms of observed daily gains or daily feed intakes, however, pigs fed SBM showed better efficiency of feed utilization and better adjusted daily gains than pigs fed CM. There were no significant interactions among the experimental treatments.

When the performance of pigs during the overall grower-finisher period (23 to 100 kg) was compared for the three high energy grains (Table 13), the differences were not significant ($P>0.05$), although the rate of gain on corn-fed pigs was about 2.5% greater than with wheat or barley and the corn-fed pigs required about 2.8% less feed. While these differences are small they represent, in effect, diets containing equal parts of Johnston barley and high energy grain.

Replacing barley with high energy grain resulted in increased daily gain without any change in daily feed intake. Daily gains adjusted to constant feed intake showed a similar trend and a strong linear relationship with the percentage of barley used in the diet ($r=-0.88$).

The regression-derived average daily gain for pigs fed barley diets was 777 g and for those fed high energy grain, without barley, was 841 g, an 8.2% increase.

The pigs fed SBM showed better daily gains and efficiency of feed conversion than those fed CM, the advantages being 3.5% for gain and 3.6% for feed efficiency. There were no significant interactions among the experimental treatments.

The high energy grains were similar in their effects on the various carcass traits (Table 14), except that the carcasses of pigs fed wheat were heavier than those fed corn. The reason for this effect is not clear but it may be a result of a higher dressing percentage ($P>0.05$) with pigs fed wheat and a higher average slaughter liveweight.

Dressing percentage improved as the dietary percentage of barley decreased and the relationship was linear ($P<0.05$). Regression values indicated 75.7% for pigs fed barley as the only grain and 77.5% for those fed high energy grain alone. This relationship was also reflected in carcass weight; 76.9 kg for barley and 78.7 for high energy grain, an increase of 2.3%.

The percentage lean yield decreased as the proportion of barley was reduced. Regression values showed barley-fed pigs having 49.2% and high energy grain-fed pigs having 47.5%, a decrease of 3.5%. Loin lean thickness was unaffected by any dietary treatments but backfat thickness increased as the percentage of barley decreased. Regression values for all-barley diets were 23.8 mm and for all high energy grain diets were 27.0 mm.

The type of protein supplement used had no effect ($P>0.05$) on any of the carcass traits. There were no significant interaction effects among any of the treatments, indicating that grain blends were the only experimental treatment that influenced carcass quality.

Carcass index showed no effects of treatments, despite there being significant differences in backfat thickness and % lean yield. It was observed that the coefficient of variation (CV) was over 20% for backfat measurements whereas the CV for dressing percentage was about 3%. There was relatively little variability in carcass index values (CV of 3 to 4%). This might imply that backfat measurements are subject to more (experimental) error than are some other measurements, however the total range among means in Table 14 with respect to cereal blends is approximately 3 mm, a narrow range.

The main conclusions that can be drawn from Table 14 are that wheat, hulless barley and corn have similar effects on carcass quality of pigs whether fed as the only grain or as blends with regular barley. Secondly, increasing proportions of high energy grains fed with barley improve the carcass yield from 100 kg liveweight pigs. Thirdly

increasing level of high energy grain reduces the yield of lean meat and increases the thickness of backfat.

Digestible energy utilization, Experiments 1 and 2

The two experiments reported here were designed to investigate the effects of various dietary concentrations of DE arising from cereal grains and protein supplements varying widely in DE contents. The diets were designed to be nutritionally adequate in other nutrients but a further test of this assumption would be to examine the pig responses in relation to DE intakes. Using DE values derived from previous studies at this institution or from published results from elsewhere, the daily DE intakes and efficiency of utilization of DE were estimated.

The estimated daily intakes of DE during the grower period of exp. 1 were similar for the two types of wheat (Table 15). Diets supplemented with SBM resulted in larger daily DE intakes than those containing CM and this prevailed with both cultivars of wheat. The percentage of barley in the grain mixture was inversely correlated (r=-0.90) with the DE intake, with 4.96 Mcal day^{-1} for all-barley diets and 5.58 Mcal day^{-1} for all-wheat diets, using values derived by regression. An interaction ($P<0.05$) involving cultivar of wheat x percentage of barley appeared to be due to an unexplained relatively high DE intake by pigs fed 75% barley and 25% Katepwa wheat, since the other values reflected the general relationship between DE intake and percentage of barley in the grain mixture.

The effects of changing the percentage of barley in the diet were more pronounced when CM was used as the supplement, as indicated by the supplement x % barley interaction ($P<0.05$).

The efficiency with which DE was utilized for gain in the grower period showed no general difference between either cultivars of wheat or kinds of protein supplement (Table 15) but the interaction ($P<0.05$) showed that SBM was superior to CM when Katepwa wheat was used but the opposite occurred with Norstar wheat. There was a high correlation (r=-0.87) between the percentage of barley in the grain mxiture and the Mcal DE used per kg liveweight gain, whereby with barley diets 7.37 Mcal were used compared with 7.91 Mcal with wheat diets. It is possible that this difference was associated with weight gains containing more fat as the percentage of wheat in the diet increased. It is also possible that the decreasing efficiency with which DE was used for gain as the dietary De level increased may have been due to an amino acid deficiency, probably lysine (Bell et al. 1988).

Daily gains were found by covariance to be significantly correlated with DE intake consequently adjusted gains were calculated (Table 15) to remove this effect. The results show that with statistically equalized DE intakes the responses to wheat cultivars were nearly identical and that the significant difference between SBM and CM with respect to DE

intakes was not associated with corresponding differences in daily gain when adjusted to a constant DE intake. As with the efficiency of utilization of DE for gain, there was a wheat x protein supplement interaction among DE-adjusted gains. With Norstar diets, requiring relatively high levels of protein supplementation, SBM was superior to CM. This was not the case with Katepwa wheat. This suggests that DE intake was a limiting factor when CM was used with the low-protein Norstar wheat, since the regression-derived adjustment failed to compensate fully.

During the finisher period (Table 15) there were no significant effects on daily DE intake of cultivar of wheat or of kind of protein supplement but there was a significant linear effect of percentage of barley in the grain mixture ($r=-0.85$). The regression values for 100 and for 0% barley were 8.58 and 9.02 Mcal DE, a 5.1% larger value for wheat compared with barley.

The efficiency of utilization of DE (Mcal DE kg gain^{-1}) showed no overall difference between the two cultivars of wheat and showed that less DE was used per kg gain when CM was the protein supplement than for SBM, however there was an interaction effect indicating that when Norstar wheat was fed there was no difference between SBM and CM diets whereas with Katepwa wheat CM-supplemented diets were more efficiently utilized than when SBM was used (Table 15). Daily gains adjusted for within-group differences in DE intake also showed that CM was superior to SBM when fed with Katepwa wheat but not with Norstar wheat.

The daily DE intakes did not differ ($P>0.05$) with the kind of high energy grain used in either the grower or finisher period of exp. 2 (Table 16), however, as the percentage of high energy grain increased from zero to 100 in the grower period there was a 6% increase in DE intake according to regression analysis. When regression analysis was applied to the % barley within each type of high energy grain this effect was greatest with hulless barley and there was no effect with increasing levels of corn. There were no significant differences in DE intakes in the finishing period due to any treatment or interaction effects, indicating that pigs were able to meet their DE requirements regardless of the grain mixture or protein supplement used whereas this was not the case with grower pigs.

Covariance analysis revealed that grower period gains were affected by within-group variability in DE intake ($P<.0001$; Table 16) consequently adjusted daily gains were calculated according to regression effects. On this basis pigs fed the hulless barley grew more slowly than pigs fed diets containing either corn or wheat. This is also indicated in the interaction effects involving the type of high energy grain x the % barley in the grain mixture. Whereas the general trend was for adjusted daily gains to decrease as the percentage of barley in the diet decreased (from 0.726 to 0.711 g; $r=0.62$), it was found that with wheat diets daily gains increased from 0.708 to 0.737 g, with hulless barley

diets gains decreased from 0.736 to 0.664 g, and with corn diets there was no change (0.731 vs 0.722 g).

When the efficiency with which DE was used for weight gain in the grower period (Table 16) was examined, it was found that diets containing hulless barley resulted in more DE per kg gain than was required with wheat or corn diets, possibly due to weight gain containing more fat with pigs fed barley even though the daily DE intakes were similar. It also appears that as the percentage of barley in the diet declined and the daily DE intakes increased the DE used per unit of gain increased. This also suggests that gains contained more fat. This general trend, as with adjusted daily gains, differed depending on the high energy grain used. In the case of wheat diets the DE used per kg gain decreased from 7.71 to 7.56 meal as barley in the diet decreased from 100 to 0% ($r=0.48$); there was no significant change with corn (7.63 vs 7.52; $r=0.22$), and with hulless barley the DE increased from 7.43 to 8.31 Mcal ($r=-0.96$). Adjusting daily gains for the grower period to a constant DE intake reversed the order compared with observed gains, indicating that the energy content (fat) of the gain had increased as the percentage of barley in the diet decreased (Table 16). The use of CM in the grower diets resulted in about 3.6% lower daily DE intake than with SBM but only 1% less ($P>0.05$) during the finisher period. The protein supplements did not differ in effects on efficiency of utilization of DE or on daily gains adjusted for DE intakes. It may be concluded that DE content was the reason for a difference in response to SBM and CM.

In the finisher period (Table 16) neither the DE utilized per kg of gain nor the adjusted daily gains revealed any treatment effects, indicating that the proportion of barley and high energy grains, the type of supplement used and the kind of high energy grain had little or no effect on DE intake or efficiency of DE utilization.

Conclusions

The two experiments described in this report have provided comparisons of barley, three types of wheat (Katepwa, Norstar and HY-320), hulless barley and corn when used as the main energy sources in the diets of growing and finishing pigs. In addition to the direct comparisons of these grains, the barley was fed in mixtures with each of the other (high energy) grains so that the grain component of diets were composed of 100, 75, 50, 25 and 0% barley, the remainder being made up of a high energy grain. In addition each diet contained either SBM or CM resulting in 50 different diets in factorial designs testing all possible combinations of 5 high energy grains, 5 blends of barley and high energy grains, and two protein supplements. The pig responses were evaluated in terms of daily gains, daily feed intake, daily DE intake, efficiency of utilization of feed and of DE, daily gains adjusted for variability in feed intake, gains adjusted for variability in DE intake and carcass traits. The main conclusions were as follows:

(1) The high energy grains varied widely in CP content (7.66 to 13.22%) and correspondingly in essential amino acids.

(2) Diets supplemented with either SBM or CM to meet recommended protein levels were adequate in all essential amino acids, except possibly lysine during the growing period.

(3) During the growing period (23 to 57 kg) the use of SBM promoted faster daily gain than CM when the low protein wheat Norstar was fed, but the supplements were similar when fed with Katepwa. In the second experiment SBM resulted in significantly better daily gains with each of these high energy grains.

(4) During the growing period daily feed intake was not affected by type of high energy grain or protein supplement used or by percentage of barley in the diet, except when Norstar wheat was used in which case SBM proved superior to CM. This apparently was because CM was lower in DE than SBM and a high level of protein supplement was needed with this low protein wheat.

(5) In the comparison of HY-320, hulless barley and corn there was little difference in daily gain among these three grains. However, gains adjusted to constant feed intake showed corn to be superior to wheat and hulless barley and when adjusted to constant DE levels corn and wheat daily gain responses were similar but greater than for hulless barley.

(6) Replacing barley with HY-320 wheat, hulless barley or corn in the grower period improved gains and feed efficiency by 3.6 to 4.0%.

(7) Finisher period responses (57 to 100 kg) showed similar daily gains for HY-320 wheat, hulless barley and corn, but as in the grower period Katepwa and Norstar wheats differed according to the protein supplement used.

(8) In the finisher period, all the high energy grains, when replacing barley, improved the daily gains, feed:gain ratios and adjusted daily gains.

(9) The high energy grains were similar in DE content but their protein contents and the amount and type of protein supplement used affected the DE content of the final diet significantly.

(10) Increasing the proportion of high energy grain in the grower diet increased the amount of DE used per unit of weight gain. This is interpreted tentatively as indicating a greater content of fat relative to lean in the tissue gain. It may also indicate a deficiency of lysine.

(11) Increasing the DE content of the finisher diet had little effect on the fat content of the weight gain, as indicated by the efficiency of utilization of DE.

(12) Dressing percentage of slaughtered pigs was improved by replacing barley with high energy grain.

(13) Percentage lean yield decreased as the proportion of barley in the diet decreased.

(14) Carcass index was reduced as the proportions of either Katepwa or Norstar wheat increased but this trend was less evident with the other high energy grains.

(15) The economic indicators derived from these experiments showed that total replacement of good quality hulled barley with high energy grains (wheat, corn, hulless barley) may result in the following responses:

(a) About 3% greater daily gain during the grower period
(b) Up to 4% less feed per unit of gain during the grower period
(c) About 12% greater gain during the finisher period
(d) About 10% less feed per unit gain during the finisher period
(e) Dressing percentage at slaughter increases from about 76 to 78%
(f) Backfat thickness increases from about 22 to 28 mm
(g) Carcass index decreases by up to 3 percentage points

Impact

The dominant factors involved in formulating rations for pigs are DE, CP and amino acids, especially lysine. Feeding standards commonly used are based largely on research done with corn-SBM diets and on pigs differing in type and breed from those commonly used in Western Canada. In addition, assessments of carcass quality are not taken into account in the feeding standards.

Research recently completed provides comparative evaluations of yellow corn, hard red spring wheat, winter wheat, HY-320 wheat, hulless barley and regular hulled barley. Each of the high energy grains replaced 0.25, 50, 75 and 100% of the regular barley in the diet and was supplemented with either SBM or CM. The results provide the necessary baseline data for estimating the effects of choice or mixture of grains on rate and efficiency of gain and on carcass quality, and similarly with respect to choice of protein supplement. By applying the appropriate cereal grain and protein supplement costs, and the market value of 100 index hog carcasses, the economic implications of specific cost-price situations may be determined.

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Table 1. Grower diet formulas (exp. 1)

Diet description							
Barley in grain mixture (%)	Protein supplement	Barley, Johnston (%)	Wheat, Katepwa (%)	Wheat, Norstar (%)	Soybean meal (%)	Canola meal (%)	Lysine[†] added (%)
Wheat, Katepwa							
100		81.12			15.24		0.09
75	Soybean	61.93	20.68		13.73		0.11
50	meal	42.00	42.13		12.18		0.14
25		21.31	64.42		10.55		0.16
0			87.41		8.85		0.19
100		76.58			4.94	14.84	0.09
75	Canola	58.77	19.63		4.48	13.46	0.11
50	meal	40.09	40.23		4.00	11.99	0.14
25		20.46	61.89		3.48	10.45	0.17
0			84.46		2.95	8.85	0.19
Wheat, Norstar							
100		81.11			15.24		0.10
75	Soybean	60.73		20.28	15.33		0.11
50	meal	40.39		40.51	15.42		0.13
25		20.09		60.70	15.52		0.14
0				80.72	15.58		0.15

(Cont.)

Table 1. (Cont.)

100		76.57		4.94	14.84	0.10
75	Canola	57.30	19.14	4.97	14.93	0.11
50	meal	38.09	38.22	5.00	15.01	0.13
25		18.94	57.25	5.03	15.09	0.14
0			76.10	5.05	15.15	0.15

† Lysine hydrochloride, 98.5%, feed grade.

Table 2. Grower diet formulas† (exp. 2)

Diet description								
Barley in grain mixture (%)	Protein supplement	Barley, Johnston (%)	HY-320 wheat (%)	Hulless barley (%)	Corn, yellow (%)	Soybean meal (%)	Canola meal (%)	Lysine added (%)
Wheat, HY-320								
100		80.56				15.84		0.06
75	Soybean	60.14	20.06			16.20		0.09
50	meal	39.90	39.96			16.40		0.13
25		19.85	59.68			16.87		0.18
0			79.21			17.19		0.21
100		75.00				5.37	16.00	0.05
75	Canola	57.50	19.13			4.87	14.75	0.09
50	meal	39.13	39.25			4.50	13.50	0.13
25		20.00	60.25			4.00	12,13	0.17
0			82.00			3.62	10.75	0.21
Hulless barley								
100		80.56				15.84		0.06
75	Soybean	60.45		20.16		15.80		0.05
50	meal	40.31		40.34		15.77		0.04
25		20.13		60.56		15.74		0.03
0				80.74		15.70		0.01

(Cont.)

Table 2. (Cont.)

100		75.00		5.37	16.00	0.05
75	Canola	56.37	18.75	5.37	16.00	0.03
50	meal	37.63	37.62	5.37	16.00	0.01
25		18.75	56.37	5.37	16.00	-
0			75.25	5.25	15.88	-
Corn						
100		80.56		15.84		0.06
75	Soybean	59.02	19.67	17.76		-
50	meal	38.43	38.44	19.58		-
25		18.78	56.33	21.34		-
0			73.46	22.99		-
100		75.00		5.38	16.00	0.05
75	Canola	54.50	18.12	6.00	17.88	-
50	meal	35.25	35.25	6.50	19.50	-
25		17.13	51.25	7.00	21.12	-
0			66.38	7.50	22.63	-

† All diets contained a mineral-vitamin supplement providing the following amounts per kg of diet: ground limestone 10 g, dicalcium phosphate 18 g, iodized salt 5 g, vitamin A 4125 IU, vitamin D_3 275 IU, vitamin E 13.5 IU, vitamin K 2 mg, thiamin 0.5 mg, riboflavin 4 mg, niacin 22 mg, pantothenic acid 16.5 mg, vitamin B_{12} 0.014 mg, choline chloride 250 mg, biotin 0.125 mg, $CuSO_4 \cdot 5H_2O$ 12.5 mg, $FeSO_4 \cdot 7H_2O$ 200 mg, $MnSO_4 \cdot 4H_2O$ 50 mg, $ZnSO_4 \cdot H_2O$ 210 mg and Na_2SeO_3 11 mg.

Table 3. Composition of cereal grains and protein supplements used in the experimental diets

Component	Wheat, Katepwa	Wheat, Norstar	Wheat HY320	Barley Scout (hulless)	Corn yellow	Barley, Johnston	Soybean meal I†	Soybean meal II	Canola† meal I	Canola meal II
Moisture (%)	11.56	9.92	12.17	12.32	13.36	11.16	11.06	11.88	11.04	10.32
Crude protein (%)	13.32	10.85	12.63	11.05	7.66	11.07	46.85	45.13	36.57	33.32
Ash (%)	1.77	1.72	1.45	1.70	1.18	2.75	5.61	5.96	6.49	6.47
Ether extract (%)	1.97	2.17	2.18	1.88	3.85	1.76	0.96	1.16	3.06	3.51
Crude fiber (%)	2.65	2.60	2.64	2.02	2.12	5.60	3.99	3.67	11.79	12.55
Nitrogen-free extract (%)	68.73	72.74	68.93	71.03	71.83	67.66	31.53	32.20	31.05	33.83
Neutral detergent fiber (%)	11.59	11.75	14.46	14.09	11.85	17.24	8.13	7.11	24.34	22.68
Acid detergent fiber (%)	3.40	3.53	2.80	2.36	2.61	7.23	4.89	4.46	17.91	17.96
Calcium (%)	0.04	0.04	0.06	0.04	0.02	0.05	0.34	0.60	0.73	0.73
Phosphorus (%)	0.36	0.35	0.33	0.38	0.27	0.36	0.61	0.67	1.00	1.11
Magnesium (%)	0.14	0.17	0.15	0.13	0.10	0.14	0.32	0.28	0.59	0.54
Copper (mg kg^{-1})	4.64	4.40	4.62	4.25	1.50	3.53	17.57	14.88	7.02	9.87
Manganese (mg kg^{-1})	32.49	28.99	41.31	13.24	4.00	14.18	32.13	36.12	43.98	63.12
Zinc (mg kg^{-1})	39.76	34.01	24.34	26.49	17.63	23.69	49.42	51.37	60.77	67.21
Iron (mg kg^{-1})	43.53	40.53	44.68	48.10	22.75	61.24	90.86	116.12	134.24	148.77
Gross energy (kcal kg^{-1})	3963	4013	3855	3904	3914	3944	4244	4101	4337	4287
(MJ kg^{-1})	16.58	16.79	16.13	16.34	16.38	16.50	17.76	17.16	18.15	17.94

(Cont.)

Table 3. (Cont.)

Arginine (%)	0.64	0.55	0.66	0.65	0.56	0.54	3.16	3.30	2.17	2.07
Histidine (%)	0.38	0.33	0.39	0.35	0.33	0.31	1.29	1.50	1.27	1.22
Isoleucine (%)	0.44	0.36	0.42	0.41	0.27	0.36	1.90	1.90	1.32	1.35
Leucine (%)	0.83	0.79	0.89	0.82	1.01	0.79	3.20	3.48	2.56	2.40
Lysine (%)	0.45	0.33	0.39	0.43	0.27	0.41	2.89	2.95	2.09	2.09
Methionine (%)	0.22	0.18	0.22	0.21	0.19	0.20	0.70	0.71	0.74	0.73
Cystine (%)	0.38	0.35	0.35	0.38	0.29	0.31	0.72	0.74	1.02	0.92
Tryptophan (%)	0.14	0.10	0.15	0.11	0.05	0.10	0.53	0.48	0.42	0.38
Phenylalanine (%)	0.64	0.51	0.61	0.60	0.43	0.57	2.20	2.34	1.42	1.37
Tyrosine (%)	0.42	0.38	0.44	0.42	0.37	0.37	1.67	1.75	1.09	1.03
Valine (%)	0.59	0.49	0.57	0.59	0.41	0.54	2.02	2.06	1.73	1.72
Threonine (%)	0.40	0.34	0.40	0.40	0.31	0.37	1.72	1.81	1.51	1.44

† Canola meals I and II contained 9.55 and 9.92 μmol glucosinolate per g fat-free sample.

‡ I and II used in exp. 1 and 2, respectively.

Table 4. Texture evaluations of cereal grains according to sieve screening. Cumulative percentages of sample retained above screen of size indicated. Assayed in triplicate.

	Diameter of sieve openings (mm)							
Cereal grain	2.38	2.00	1.68	1.41	1.19	1.00	0.84	<0.84
Wheat†								
Katepwa	16.2	32.7	54.4	69.0	80.7	85.8	88.0	100.0
	4.7	15.9	34.6	55.8	72.4	80.3	84.5	100.0
	11.4	31.5	52.7	69.2	80.2	85.8	88.4	100.0
Norstar	22.4	39.0	55.6	68.4	78.7	83.4	85.9	100.0
	13.1	32.4	53.8	71.2	82.7	87.7	90.0	100.0
	13.3	34.8	55.7	71.3	82.0	86.9	88.9	100.0
HY-320	44.8	61.8	75.3	83.5	88.2	90.3	91.6	100.0
	36.2	54.3	69.4	79.5	85.9	87.9	90.0	100.0
	25.6	41.6	56.9	67.8	75.9	78.6	81.6	100.0
Barley‡								
Johnston	13.9	23.0	34.2	47.6	59.5	68.4	73.1	100.0
	18.5	29.0	40.0	54.4	65.3	73.2	78.0	100.0
	18.5	28.4	38.8	51.3	63.6	71.7	76.0	100.0
	42.5	54.9	66.2	76.6	83.8	88.0	90.3	100.0
	48.7	60.5	70.2	78.5	85.2	87.3	89.4	100.0
	33.5	45.4	57.3	67.9	77.3	80.2	84.4	100.0
Scout	46.2	61.9	73.8	83.7	89.1	92.1	93.5	100.0
	45.0	58.7	69.3	77.3	83.7	86.4	88.9	100.0
	41.6	56.1	67.4	76.0	82.2	84.7	87.1	100.0
Corn, yellow‡	18.6	29.8	41.4	53.6	63.1	69.8	73.4	100.0
	13.0	22.0	32.2	41.3	50.8	55.6	62.3	100.0
	8.7	15.2	22.8	32.5	42.8	48.3	56.3	100.0

† Processed in a roller mill.

‡ Processed in a hammermill, 0.64 mm screen.

Table 5. Nutrient composition of grower diets (exp. 1)

High energy grain	Protein supplement	Barley in grain mix (%)	Moisture (%)	Crude protein (%)	Calcium (%)	Digestible energy† (kcal kg^{-1})	Lysine (%)	Isoleucine (%)	Methionine + cystine§ (%)	Tryptophan§ (%)
Katepwa		100¶	11.80	15.93	0.88	2982	0.83	0.58	0.63	0.16
wheat	SBM‡	50	11.44	16.50	0.91	3039	0.87	0.63		
		0	11.02	17.85	1.10	3102	0.85	0.58	0.65	0.17
		100	11.80	16.15	0.88	2944	0.84	0.59	0.72	0.17
	CM‡	50	11.46	16.80	1.03	3011	0.80	0.60		
		0	10.79	18.05	1.00	3084	0.83	0.65	0.71	0.17
Norstar		100	11.73	16.02	0.87	2981	0.88	0.62	0.63	0.16
	SBM	50	11.33	15.78	0.99	3061	0.85	0.61		
		0	10.74	15.91	1.13	3141	0.86	0.62	0.64	0.16
		100	11.93	15.85	0.88	2943	0.84	0.60	0.72	0.17
	CM	50	11.44	15.86	0.98	3019	0.88	0.63		
		0	10.97	15.90	0.84	3096	0.84	0.63	0.74	0.17
Required level, NRC 20-35 kg pig			(10.0)	16.0	0.60	3380	0.70	0.50	0.45	0.12
	35-60 kg pig		(10.0)	14.0	0.55	3390	0.61	0.44	0.40	0.11

† Estimated from published data. See text.

‡ SBM = soybean meal; CM = canola meal.

§ Only the 100 and 0% barley diets were analyzed.

¶ The values for 75 and 25 % barley were intermediate in relation to adjacent values.

Table 6. Growth and feed utilization responses of pigs during the grower period (23 to 57 kg) (exp. 1)

Treatment		Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
Wheat					
Katepwa		691	1.76	2.56	690
Norstar		702	1.76	2.53	703
Percentage barley in grain mixture					
100		669	1.70	2.56	684
75		700	1.78	2.55	695
50		690	1.76	2.55	690
25		712	1.78	2.50	712
0		706	1.79	2.55	701
Supplement					
Soybean meal (SBM)		708	1.77	2.51	706
Canola meal (CM)		683	1.76	2.58	687
Wheat x supplement interaction					
Katepwa	SBM	689*ab*[†]	1.76	2.57*ab*	688*b*
	CM	691*ab*	1.76	2.55*ab*	692*ab*
Norstar	SBM	727*a*	1.77	2.46*b*	724*a*
	CM	675*b*	1.75	2.62*a*	681*b*
Supplement x percentage of barley					
SBM	100	700	1.74	2.50	705
	75	750	1.84	2.46	727
	50	670	1.72	2.58	681
	25	699	1.76	2.53	698
	0	720	1.77	2.46	719

(Cont.)

Table 6. (Cont.)

CM	100	637	1.67	2.61	663
	75	651	1.71	2.64	664
	50	710	1.80	2.53	700
	25	728	1.80	2.47	725
	0	695	1.80	2.64	682
Error mean square		3341	.0180	.0362	2124
Degrees of freedom		59	59	59	58

Table 7. Growth and feed utilization responses of pigs during the finisher period (57 to 100 kg) (exp. 1)

Treatment		Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
Wheat					
Katepwa		840	2.95	3.54	827
Norstar		842	2.87	3.44	856
Percentage barley in grain misture					
100		794	2.92	3.67	789
75		799	2.85	3.59	818
50		868	2.96	3.47	849
25		852	2.88	3.39	863
0		892	2.92	3.31	888
Supplement					
Soybean meal (SBM)		828	2.91	3.55	826*b*†
Canola meal (CM)		854	2.90	3.43	857*a*
Wheat x supplement interaction					
Katepwa	SBM	812	2.97	3.69*a*	791*b*
	CM	869	2.92	3.39*b*	862*a*
Norstar	SBM	844	2.86	3.41*b*	861*a*
	CM	838	2.87	3.48*b*	851*a*
Supplement x percentage of barley					
SBM	100	791	2.93	3.71	782
	75	835	2.96	3.57	818
	50	806	2.92	3.68	802
	25	827	2.87	3.48	838
	0	884	2.88	3.29	891

(Cont.)

Table 7. (Cont.)

CM	100	797	2.91	3.66	797
	75	763	2.75	3.61	818
	50	931	3.01	3.26	898
	25	880	2.88	3.29	888
	0	901	2.95	3.30	886
Error mean square		13,328	0.0749	0.0869	4669
Degrees of freedom		59	59	59	58

Table 8. Growth and feed utilization responses of pigs during the overall grower-finisher period (23 to 100 kg) (exp. 1)

Treatment		Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
Wheat					
Katepwa		770	2.41	3.15	761*b*
Norstar		775	2.36	3.07	785*a*
Percentage barley in grain mixture					
100		737	2.38	3.24	737
75		754	2.38	3.17	756
50		783	2.40	3.09	778
25		784	2.37	3.03	792
0		805	2.39	3.00	803
Supplement					
Soybean meal (SBM)		772	2.40	3.12	767
Canola meal (CM)		772	2.37	3.09	779
Wheat x supplement interaction					
Katepwa	SBM	756	2.44	3.24*a*	738*c*
	CM	783	2.38	3.05*b*	784*b*
Norstar	SBM	789	2.36	3.01*b*	796*a*
	CM	761	2.35	3.13*ab*	775*b*
Supplement x percentage barley					
SBM	100	748	2.41	3.23	738
	75	795	2.46	3.10	770
	50	744	2.38	3.23	745
	25	768	2.38	3.10	769
	0	807	2.37	2.96	811

(Cont.)

Table 8. (Cont.)

CM	100	726	2.35	3.25	736
	75	712	2.30	3.23	742
	50	821	2.41	2.95	810
	25	803	2.36	2.94	815
	0	802	2.41	3.05	794
Error mean square		5995	.0205	.0457	2667
Degrees of freedom		59	59	59	58

Table 9. Carcass traits of pigs in exp. 1

Treatment		Dressing percentage (%)	Carcass weight (kg)	Backfat thickness (mm)	Lean yield (%)	Loin thickness (mm)	Carcass index
Wheat							
Katepwa		77.7	79.0*a*†	24.39	48.54	51.39	104.2
Norstar		77.1	77.5*b*	24.73	48.36	49.78	103.7
Percentage barley in grain mixture							
100		76.0*b*	77.2	22.78	49.09*a*	53.28	104.9*ab*
75		77.2*ab*	77.9	22.57	49.09*a*	52.33	105.3*a*
50		78.0*a*	78.5	23.22	48.58*ab*	46.72	104.6*abc*
25		78.3*a*	79.5	26.80	47.86*b*	50.93	102.8*bc*
0		77.7*ab*	78.3	27.60	47.65*b*	49.90	102.2*c*
Supplement							
Soybean meal (SBM)		77.7	78.5	25.99*a*	48.1*b*	50.62	103.3
Canola meal (CM)		77.2	78.0	23.08*b*	48.8*a*	50.61	104.6
Wheat x supplement interaction							
Katepwa	SBM	78.2	79.4	25.70	48.26	52.57	104.0
	CM	77.2	78.6	23.05	48.82	50.20	104.4
Norstar	SBM	77.1	77.6	26.29	47.86	48.55	102.6
	CM	77.1	77.4	23.08	48.86	51.08	104.7

(Cont.)

Table 9. (Cont.)

Supplement x percentage barley							
SBM	100		76.6	23.94	48.72	52.44*abcd*	103.9
	75		76.8	23.64	48.63	49.29*bcd*	104.1
	50		79.4	25.69	47.95	47.25*d*	103.6
	25		80.5	27.69	47.49	48.81*cd*	102.5
	0		79.1	28.69	47.59	55.13*ab*	102.6
CM	100		78.1	21.62	49.15	54.62*ab*	105.9
	75		77.2	21.62	48.65	52.62*abcd*	106.4
	50		79.8	20.75	49.07	47.87*cd*	105.5
	25		81.5	25.79	47.67	51.12*abcd*	103.1
	0		80.5	26.38	46.72	56.62*a*	101.7
Wheat x percentage barley							
Katepwa	100	76.5	78.6	21.37*cd*	49.60*a*	55.31	106.1*ab*
	75	77.1	78.2	23.56*bcd*	48.89*abc*	53.62	104.9*abc*
	50	78.2	78.6	19.87*d*	49.50*a*	47.19	106.6*a*
	25	78.7	80.1	27.06*ab*	47.80*cd*	51.19	102.7*bcd*
	0	78.1	79.4	30.06*a*	46.90*d*	49.62	100.7*d*
Norstar	100	75.4	75.7	24.19*bc*	48.57*abc*	51.25	103.6*abcd*
	75	77.3	77.5	21.43*cd*	49.31*ab*	50.86	105.9*abc*
	50	77.8	78.4	26.56*ab*	47.65*cd*	46.25	102.5*cd*
	25	77.8	78.8	26.50*ab*	47.93*bcd*	50.64	102.9*bcd*
	0	77.4	77.2	24.79*bc*	48.40*abc*	50.21	103.6*abcd*
Error mean square		.0005	8.377	14.352	1.861	46.988	9.671
Error degrees of freedom		58	58	59	58	57	58

† Means within comparison groups followed by the same letter, or no letters, are not significantly different P=0.05).

Table 10. Composition of grower diets

High energy grain	Protein supplement	Barley in grain mix (%)	Moisture (%)	Crude protein (%)	Calcium (%)	Zinc (mg kg^{-1})	Digestible energy (kcal kg^{-1})	Lysine (%)	Isoleucine (%)	Methionine + cystine (%)	Tryptophan (%)
Wheat, HY320	SBM	100	11.09	16.22	1.04	147	2994	0.86	0.55	0.64	0.16
		50	11.44	16.50	1.34	189	3017	0.95	0.62		
		0	12.32	16.53	1.29	165	3048	0.87	0.58	0.64	0.18
	CM	100	11.17	16.30	1.04	135	2938	0.83	0.56	0.72	0.16
		50	11.59	16.60	1.30	170	2965	0.90	0.60		
		0	11.97	17.45	1.66	200	2994	1.00	0.65	0.69	0.18
Barley, Tupper	SBM	100	11.23	16.26	1.06	125	2994	0.82	0.65	0.64	0.16
		50	11.82	17.21	1.25	145	3126	0.80	0.64		
		0	12.13	17.13	1.69	183	3256	0.80	0.61	0.70	0.16
	CM	100	10.95	16.43	1.05	144	2938	0.80	0.58	-	0.16
		50	11.37	16.54	1.19	145	3068	0.77	0.60		
		0	11.96	16.74	1.19	171	3183	0.80	0.59	0.78	0.16
Corn, yellow	SBM	100	11.17	16.79	1.49	207	2994	0.81	0.56	-	-
		50	11.77	16.13	1.00	162	3124	0.85	0.61		
		0	12.41	16.63	1.04	154	3241	0.90	0.60	0.68	0.15
	CM	100	11.24	16.74	1.06	178	2939	0.90	0.60	-	-
		50	11.71	15.94	0.80	137	3049	0.86	0.56		
		0	12.04	16.65	0.96	159	3141	0.83	0.61	0.80	0.16

Table 11. Growth and feed utilization responses of pigs during the grower period (23 to 57 kg) (exp. 2)

Treatment	Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
High energy grain				
Wheat, HY-320	714*a*†	1.81*a*	2.54*a*	709*b*
Barley, hulless, Tupper	704*a*	1.79*a*	2.54*a*	708*b*
Corn, yellow	730*a*	1.79*a*	2.46*b*	732*a*
Percentage of barley in grain misture				
100	707*a*	1.80*a*	2.55*a*	705*a*
75	710*a*	1.80*a*	2.54*a*	709*a*
50	709*a*	1.76*a*	2.54*a*	709*a*
25	719*a*	1.84*a*	2.48*a*	730*a*
0	736*a*	1.78*a*	2.46*a*	727*a*
Supplement				
Soybean meal	734*a*	1.81*a*	2.47*b*	729*a*
Canola meal	698*b*	1.78*a*	2.56*a*	703*b*
Error mean square (90 d.f.‡)	5442	0.0276	0.0248	1946

† See footnotes Table 6.

‡ For adjusted daily gains 89 degrees of freedom were used.

Table 12. Growth and feed utilization responses of pigs during the finisher period (57 to 100 kg) (exp. 2)

Treatment	Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
High energy grain				
Wheat, HY-320	899a[†]	3.02a	3.40a	898a
Barley, hulless, Tupper	901a	3.02a	3.37a	898a
Corn, yellow	912a	2.99a	3.30a	916a
Percentage of barley in grain mixture				
100	858c	3.07a	3.60a	840d
75	893bc	3.02a	3.41b	891bc
50	879bc	2.98a	3.43b	887c
25	963a	2.99a	3.12c	968a
0	926ab	2.98a	3.23c	935ab
Supplement				
Soybean meal	917a	3.00a	3.30b	919b
Canola meal	891a	3.01a	3.41a	889a
Error mean square (90 d.f.)	10,235	0.0527	0.0882	6285[‡]

† See footnotes Table 6.

‡ See footnotes Table 11.

Table 13. Growth and feed utilization responses of pigs during the entire grower-finisher period (23 to 100 kg)(exp. 2)

Treatment	Daily gain (g)	Daily feed (kg)	Feed: gain ratio	Adjusted daily gain (g)
High energy grain				
Wheat, HY-320	811a†	2.45a	3.06a	810a
Barley, hulless, Tupper	808a	2.46a	3.05a	810a
Corn, yellow	831a	2.46a	2.97a	831a
Percentage of barley in grain mixture				
100	789b	2.51a	3.19a	777c
75	804ab	2.47a	3.07a	805c
50	805ab	2.46a	3.07a	804c
25	837ab	2.42a	2.94b	859a
0	849a	2.45a	2.86b	841b
Supplement				
Soybean meal	831a	2.46a	2.97b	831a
Canola meal	803a	2.46a	3.08a	803b
Error mean square (87 d.f.)	5623	0.0320	0.0483	3357‡

† See footnotes Table 6.

‡ See footnotes Table 11.

Table 14. Carcass characteristics

Treatment	Dressing percentage (%)	Carcass weight (kg)	Lean yield (%)	Loin thickness (mm)	Backfat thickness (mm)	Carcass index
High energy grain						
Wheat, HY-320	77.3a†	78.6a	48.5a	51.0a	24.9a	104.0a
Barley, hulless, Tupper	76.3a	77.5ab	48.0a	49.0a	26.2a	102.8a
Corn, yellow	76.2a	77.3b	48.7a	50.1a	25.1a	104.5a
Percentage of barley in grain mixture						
100	75.8b	76.8b	49.2a	50.6a	22.8c	105.1a
75	76.2b	77.4ab	48.9ab	49.1a	26.0abc	103.0a
50	76.6ab	77.9ab	48.1abc	50.5a	26.5ab	102.6a
25	76.9ab	78.3ab	47.9bc	50.4a	23.8bc	105.0a
0	77.7a	78.6a	47.6c	49.9a	27.9a	103.1a
Supplement						
Soybean meal	77.0a	78.1a	48.3a	50.8a	25.8a	103.7a
Canola meal	76.3a	77.5a	48.5a	49.5a	25.0a	103.9a
Error mean square	0.0005	5.934	3.069	36.04	27.58	14.70
Error degrees of freedom‡	87	87	72	72	85	86

† See footnotes Table 6.

‡ Reduced from 90 because of missing data.

Table 15. Daily digestible energy (DE) intake, efficiency of utilization of DE for weight gain and daily gains adjusted for within-group variation in DE intake, for grower (23 to 57 kg) and finisher pigs (57 to 100 kg) (exp. 1)

Treatment	Grower period			Finisher period			
	Daily DE intake (Mcal kg^{-1})	DE $kg\ gain^{-1}$ (Mcal)	Adjusted daily gain (kg)	Daily DE intake (Mcal kg^{-1})	DE $kg\ gain^{-1}$ (Mcal)	Adjusted daily gain (kg)	Carcass index
Wheat							
Katepwa	5.23	7.59	0.696	8.92	10.71	0.829	104.3
Norstar	5.36	7.69	0.698	8.71	10.46	0.854	103.6
Protein supplement							
Soybean meal (SBM)	5.41*a*	7.66	0.699	8.87	10.82*a*	0.821*b*	103.4
Canola meal (CM)	5.18*b*	7.62	0.695	8.74	10.34*b*	0.863*a*	104.5
Barley in grain (%)							
100	4.83	7.24	0.710	8.65	10.92	0.813	104.8
75	5.34	7.64	0.696	8.55	10.77	0.829	105.1
50	5.33	7.74	0.687	8.91	10.53	0.850	104.7
25	5.44	7.66	0.703	8.83	10.40	0.852	102.9
0	5.54	7.91	0.687	9.06	10.28	0.865	102.3
Wheat x supplement							
Katepwa SBM	5.37	7.81*ab*	0.682*b*	9.02	11.21*a*	0.789*b*	104.1
Katepwa CM	5.10	7.36*c*	0.709*ab*	8.81	10.20*b*	0.869*a*	104.4
Norstar SBM	5.44	7.51*bc*	0.715*a*	8.75	10.42*b*	0.852*a*	102.7
Norstar CM	5.27	7.88*a*	0.681*b*	8.67	10.50*b*	0.856*a*	104.6

(Cont.)

Table 15. (Cont.)

Wheat x % barley								
Katepwa	100	4.57	6.93	0.723	8.80	10.71	0.825	106.1
	75	5.53	7.64	0.704	8.73	11.38	0.780	104.8
	50	5.26	7.78	0.681	9.03	10.62	0.846	106.7
	25	5.34	7.76	0.685	8.87	10.49	0.842	102.8
	0	5.47	7.82	0.685	9.15	10.33	0.853	100.9
Norstar	100	5.09	7.54	0.697	8.49	11.12	0.801	103.4
	75	5.15	7.64	0.690	8.37	10.16	0.879	105.4
	50	5.41	7.70	0.694	8.94	10.45	0.853	102.6
	25	5.56	7.54	0.721	8.78	10.30	0.863	103.0
	0	5.61	7.99	0.688	8.98	10.23	0.876	103.7
Supplement x % barley								
SBM	100	5.22	7.48	0.707	8.74	11.08	0.799	103.7
	75	5.59	7.45	0.724	8.92	10.78	0.824	104.2
	50	5.26	7.87	0.673	8.90	11.23	0.796	103.6
	25	5.44	7.81	0.686	8.87	10.73	0.812	102.5
	0	5.51	7.69	0.701	9.00	10.27	0.863	102.7
CM	100	4.44	6.99	0.713	8.56	10.76	0.826	105.7
	75	5.09	7.83	0.669	8.19	10.77	0.834	106.0
	50	5.40	7.62	0.701	9.06	9.83	0.903	105.6
	25	5.45	7.49	0.719	8.79	10.03	0.883	103.3
	0	5.56	8.12	0.672	9.12	10.29	0.867	101.9
Error mean square (59 d.f.)		0.1614	0.3362	0.0021	0.6920	0.7984	0.0046	9.58

Table 16. Daily digestible energy (DE) intake, DE per kg gain and daily gain adjusted for within-group variation in DE intake, for grower and finisher periods (exp. 2)

Treatment	Grower period			Finisher period		
	DE intake meal (kg^{-1})	DE kg^{-1} gain (Mcal)	Adjusted gain (kg)	DE intake (Mcal kg^{-1})	DE kg^{-1} gain (Mcal)	Adjusted gain (kg)
High energy grain						
Wheat, HY-320	5.41	7.61*b*	0.722*a*	8.99	10.12	0.917
Barley, hulless, Tupper	5.53	7.87*a*	0.699*b*	9.35	10.44	0.886
Corn, yellow	5.52	7.58*b*	0.727*a*	9.21	10.15	0.908
Percentage of barley in grain mixture						
100	5.34	7.57	0.724	9.09	10.66	0.866
75	5.42	7.66	0.718	9.09	10.25	0.903
50	5.47	7.76	0.709	9.09	10.46	0.886
25	5.49	7.62	0.721	9.26	9.66	0.955
0	5.72	7.81	0.709	9.38	10.19	0.909
Supplement						
Soybean meal	5.59*a*	7.63	0.723	9.23	10.14	0.913
Canola meal	5.39*b*	7.74	0.710	9.13	10.34	0.894
High energy grain x % barley						
Wheat 100	5.39	7.71	0.710	9.23	10.96	0.842
75	5.21	7.67	0.714	8.95	10.02	0.924
50	5.49	7.64	0.722	8.89	10.69	0.865

Table 16. (Cont.)

	25	5.39	7.54	0.729	9.08	9.24	0.999
	0	5.59	7.48	0.738	8.76	9.63	0.953
Barley, hulless	100	5.14	7.45	0.731	9.05	10.52	0.873
	75	5.41	7.72	0.715	8.99	10.37	0.894
	50	5.43	7.77	0.705	9.23	10.32	0.903
	25	5.72	7.99	0.690	9.62	10.19	0.907
	0	5.97	8.43	0.655	9.83	10.81	0.852
Corn	100	5.49	7.54	0.731	8.99	10.47	0.881
	75	5.64	7.59	0.726	9.31	10.37	0.889
	50	5.56	7.88	0.700	9.18	10.35	0.889
	25	5.31	7.35	0.744	9.07	9.57	0.959
	0	5.59	7.52	0.733	9.48	10.05	0.922
Error mean square (90 d.f.)		0.2579	0.2311	0.0019	0.4923	0.8064	0.0063
Error degrees of freedom		90	90	90	87	87	86